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Suitability of rubber concrete for railway sleepers☆

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Summary An experimental investigation by replacing 15% by volume fraction of fine aggregate by crumb rubber was conducted to find the fatigue failure load and impact resistance. The design strength of 50 and 55 MPa was achieved. Test result indicated that there was reduction in compressive strength and modulus values. The fatigue failure and impact resistance were high for rubber concrete when compared with ordinary high strength concrete. The impact strength for railway sleeper with crumb rubber replacement showed increase of about 60% when compared to prestressed concrete sleeper.

Introduction

Railway sleeper is a main component of railway track structure. Its function is to distribute loads from the rail foot to the underlying ballast bed. By passing train wheels the loads applied by the rail head will be in the form of impact loads. Sleepers are provided to resist repetitive impact stress from dynamic interactions between the train and track infrastructure in services. Adding crumb rubber to a concrete matrix edge to a significant increase in its toughness, so impact resistance. It is also observed that the utilization of discarded rubber tyres in concrete to replace a part of the fine aggregate has resulted in a concrete which has high impact resistance, improved elastic properties and considerable fatigue strength. The studies observed that stiffness increased under cyclic load for concrete with recycled tyre rubber crumbs. The dynamic response of railway concrete sleepers was studied to determine the required amount of energy to fail the sleeper under sudden load. The impact resistance of the railway concrete sleepers was most likely of splitting mode due to the lack of bonding between bars and concrete under dynamic circumstances (Remennikov and Kaewunruen, 2007). The literature study on crumb rubber reveals that the presence of small sized crumb rubber in concrete increased its resistance to crack commencement under impact load (Sallam et al., 2008). The result of above reviews indicates that the addition of fine crumb rubber tyre to the cement concrete reduces the compressive strength to the extend depending on the percentage of rubber added but improves the ductility property. Addition of fine rubber crumbs improves fatigue and impact resistances compared to ordinary concrete.

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Table 1 Specimen details.

S. No.	Type of concrete	Identification
1	Mix-1 without crumb rubber	M50R0
2	Mix-1 with 15% volume fraction of fine aggregate replaced by crumb rubber.	M50R15
3	Mix-2 without crumb rubber	M55R0
4	Mix-2 with 15% volume fraction of fine aggregate replaced by crumb rubber.	M55R15
5	Prestressed concrete	P50R0
6	Prestressed concrete	P55R0

Materials used

The cement used in the present study was Ordinary Portland Cement 53 Grade, conforming to IS 12269:1987. Locally available river sand passing through IS Sieve 4.75 mm conforming to Zone II of IS 383:1970 of specific gravity 2.62 was used as fine aggregate. Crushed aggregate with maximum size of 12.5 mm with specific gravity of 2.81 was used as coarse aggregate. Fine rubber was obtained from local rubber retrading centres. Bulk density and specific gravity of fine rubber is 0.498 and 0.894 kg/m^3 respectively. This fine rubber was further sieved to conform to the same size and grading as that of fine aggregate. Silica fume (amorphous SiO_2) named Elkem micro silica of grade 920D from Elkem Materials Mumbai was used. Super plasticizing admixture (Conplast SP430) based on selected sulphonated naphthalene polymers was used to obtain the required workability for the mix.

Mix design

The mix design was done as per IS 10262:2009, Indian Railway standard specification for pre-tensioned prestressed concrete sleepers for broad gauge and metre gauge, serial No. T-39 (fourth revision Aug 2011), MORTH (Ministry of Road Transport and Highways) Specification Section 1700 (structural Concrete) and IRS (Indian Railway Standard) Concrete Bridge Code 1997 for M50 and M55. The specimen details are shown in Table 1 and experiment details in Table 2.

Experiments

Fatigue strength

Fatigue test is conducted on a hydraulic controlled repeated load test setup having capacity 0—5 T. The span and points of loading were kept same as for flexural test. Constant amplitude loads were applied at a suitable frequency of 2 Hz. Stress level is defined as the ratio of applied maximum cycle stress to the mean static flexural strength. The maximum stress level applied ranged from 70% to 60% of the static flexural strength for the specimen. The number of cycles to failure of specimen under different load condition will be noted as fatigue life N.

Impact test

The instrument was made according to ACI 544.2R-89. Foamed elastomer pieces were placed between the specimen and positioning legs to restrain movement of specimen during testing. The hammer is dropped repeatedly over the specimen and the number of blows required for first visible crack and ultimate failure was recorded. The blows can be converted in to impact energy.

$$\text{Impact Energy} = \text{Potential Energy} = M \times g \times H \times N = \frac{W}{g} \times g \times H \times N = W \times H \times N \quad (\text{Nm})$$

where H — height of drop, W — weight of the hammer, N — number of blows.

Railway sleeper mould is modelled using law of similitude (mass based law), since the effect on gravity loads is more important. For the present model the stress factor S_f, acceleration scale factor $\left(Sa = \frac{1}{S_L}\right)$ and the geometric (length) factor S_L. $S_L = 3$; $S_f = 1$; $S_a = 0.33$. The scaled down model is shown in Fig. 1 (Brideman, 1931).

Impact load test (DPSCS)

The wheel of 500 kg weight shall be tied with one end of a wire rope and the other end of the wire rope is attached with the lifting and pulling machine. The wheel shall be positioned at the height of 75 cm from the edge of sleeper and dropped freely releasing the lever of pulling machine on both ends of the sleeper at two locations. The wheel shall be dropped twice at each of four locations on the sleeper. Scaled down mass of thickness 63 mm which is equal to thickness of wheel of train and height 250 mm is used for the study. The test setup is shown in Fig. 2. The drop test was done only at one location i.e. 280 mm away from the centre line of the rail towards centre of sleeper.

Table 2 Experiment details.

S. No.	Experiment	Specimen	Dimension (mm)
1.	Fatigue strength	Prisms	100 × 100 × 500
2.	Impact strength (Drop weight type ACI 544.2R-89)	Cylinder	Diameter — 150Height — 63.5
3.	Impact strength	Railway sleeper	Fig. 1

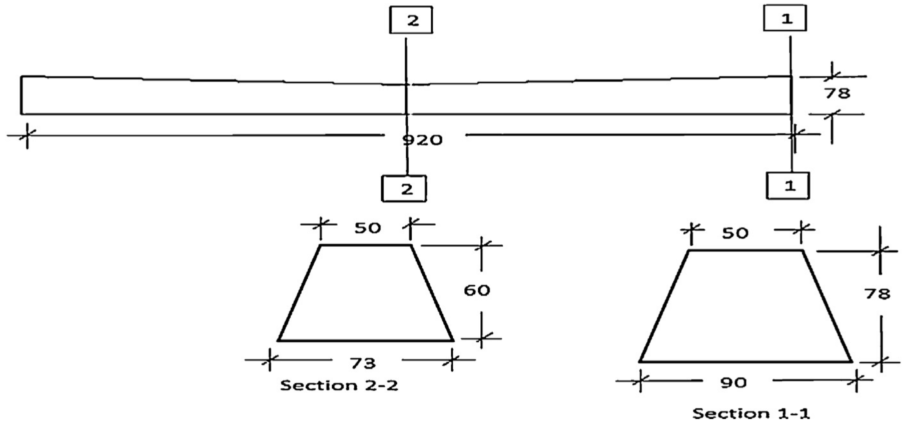

Figure 1 Details of model specimen.

Figure 2 Test setup for impact test on railway sleeper.

Results and discussion

Impact strength

Table 3 shows the impact strength of concrete with and without rubber.It was clear from the results that the percentage increase in impact resistance was high for lower grade concrete. But adding the rubber to the concrete produced significant increase in the number of blows. The impact resistance of crumb rubber concrete was enhanced by 50% when compared to ordinary concrete.

Table 3 Impact strength of different mixes.

Identification	Impact strength (Nm)	
	First crack (Avg)	Ultimate crack (Avg)
M50R0	4502.88	4789.62
M50R15	9520.83	9701.37
M55R0	10,726.2	11,257.2
M55R15	19,997.46	20,119.59

Table 4 Fatigue failure load for different mixes.

S. No.	Identification	Normalized stress level, *S*	Failure load (N)
1	M50R0	0.7	251.43
		0.6	323.34
2	M50R15	0.7	1314.83
		0.6	502.96
3	M55R0	0.7	675.42
		0.6	965.99
4	M55R15	0.7	1343.58
		0.6	1156.8

Fatigue strength

The fatigue failure load obtained for different mixes is shown in Table 4.

The failure load for M50R15 was about 81% higher than M50R0 even though, difference in number of cycles to failure when crumb rubber was added in concrete was low. In the case of M55R15 the percentage increase in failure load was only 50% when compared with M55R0.

Impact test on railway sleeper

The results obtained after drop weight impact test on railway sleeper is shown in Table 5. As per the draft provisional

Table 5 Impact test results on sleeper models.

Type of concrete	Impact strength (Nm)	
	First crack	Ultimate crack
M50R0	95	523.50
M50R15	617.5	1520
M55R0	142.5	712.50
M55R15	380	1235
P50R0	285	570
P55R0	332.5	760

Figure 3 Crack pattern of ordinary, rubber and prestressed concrete.

specification of composite sleeper (DPSCS), the acceptance criteria after impact test is that only recess should be formed but no crack should appear on the surface of the sleeper. All specimens made with crumb rubber replacement do not show any crack after two blows. M50R15 shows 66% increase in impact strength when compared to M50R0. M55R15 shows 42% increase in impact strength when related to M55R0. Concrete with crumb rubber shows 40—60% increase in impact strength when compared to prestressed concrete sleeper without rubber. Fig. 3 shows the crack pattern of ordinary, crumb rubber and prestressed concrete sleeper.

Conclusions

Experimental investigations were carried out to study the mechanical properties like fatigue strength and impact resistance of rubber concrete and ordinary concrete as per Indian standards and ACI standards. The following conclusions are arrived at.

1. Presence of crumb rubber in concrete has increased the resistance to crack initiation under impact load by 80—110%.
2. Impact load at failure was 50% high for concrete with crumb rubber. This is due to the energy absorption capacity of the crumb rubber.
3. Failure cycle for the crumb rubber concrete was high which increases the damage life.
4. In railway sleeper, presence of crumb rubber shows 40—60% increase in impact strength when compared to prestressed concrete sleeper.

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